E3S Web of Conferences **382**, 16006 (2023)
UNSAT 2023
https://doi.org/10.1051/e3sconf/202338216006

Evaluating the performance of three sensor types for long-term measurement of suctions in gold tailings

Yashay Narainsamy[1*] and *Schalk Willem* Jacobsz[1]

[1]University of Pretoria, Department of Civil Engineering, Pretoria, South Africa

Abstract. A key aspect of the stability of a tailings dam is the pore pressure regime within the dam. Although gold tailings can exist in an unsaturated state in the field, the measurement of negative pore pressures (matric suctions) in active gold tailings dams is not common. One of the reasons for this may be the uncertainty regarding the ideal sensor type that should be used due to the shortcomings of various types of sensors. To investigate this, a long-term Drying Box experiment was conducted in the geotechnical laboratory at the University of Pretoria. Three sensor types were assessed: a commercially available water potential sensor and two versions of the TUKS tensiometer – a high capacity tensiometer designed and constructed at the University of Pretoria. Gold tailings was deposited in a slurry form and allowed to desiccate. The response from the three sensor types as a result of the change in suctions due to drying and subsequent re-wetting were observed. It was found that the TUKS tensiometer with the steel casing provided rapid, reliable, long-term suction readings. This sensor type is therefore recommended for long-term measurement of suction in gold tailings.

1 Introduction

A key aspect of the stability of a tailings dam is the pore pressure regime within the dam. It is common practice to measure the positive pore pressures in a tailings dam and to use these values in safety evaluations. Although it is known that gold tailings can exist in an unsaturated state in the field [1], the measurement of negative pore pressures (matric suctions) in active gold tailings dams is not common.

One of the reasons for this may be the uncertainty regarding the ideal sensor type that should be used, specifically relating to sensor damage due to potential chemical reactions within the tailings and the performance of such sensors in the long term. Another consideration may be the ability of the sensor to capture the rapid changes in suctions due to the routine wetting and drying cycles from deposition or rainfall events, which is key to understanding the stresses imposed on the tailings. To investigate the performance of the sensor types, a long-term Drying Box experiment was conducted in the geotechnical laboratory at the University of Pretoria.

1.1 Gold tailings

The gold tailings used in this study was obtained from an active tailings dam in South Africa. The Mine is located in the East Rand of Gauteng and mining is from the Witwatersrand Supergroup. The tailings dam is an upstream constructed facility, and the material was sourced near the outer wall. A typical particle size distribution of the gold tailings is shown in Fig. 1. The material has a median grain size (D_{50}) of 63 μm and classifies as an inorganic silt of low plasticity (ML) [2].

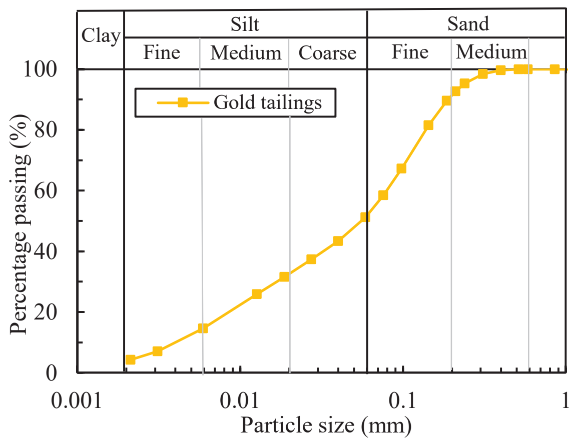

Fig. 1. Typical particle size distribution of the gold tailings

A Soil Water Retention Curve (SWRC) was measured for the gold tailings using the tensiometer method and the results are shown in Fig. 2. The sample was prepared using the Moist Tamping sample preparation method and was created at a void ratio of 0.96 which is similar to the in-situ void ratio of the material. This is important as it is known that the SWRC is void ratio dependent [3]. An Air Entry Value (AEV) of 9 kPa was determined for the material which, although near the lower bound, is in line with the findings of other researchers for similar materials [4,5]. The shape of the SWRC is typical for a sandy soil and

* Corresponding author: yashay.narainsamy@tuks.co.za

 https://doi.org/10.1051/e3sconf/202338216006

shows good fit with common SWRC estimate methods [6].

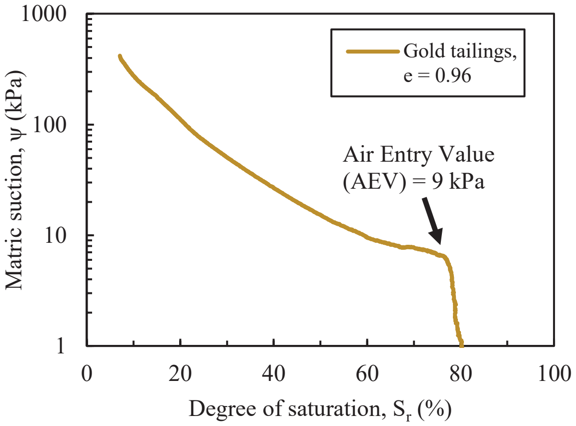

Fig. 2. Soil Water Retention Curve (SWRC) of the gold tailings

2 Sensor types

Three different sensor types were used for the experiment.

The first sensor type is a commercially available Water Potential Sensor (WPS) from the METER Group, referred to as a TEROS 21 sensor. This sensor comprises two fixed-matrix porous ceramic discs separated by a printed electric circuit board [7]. By measuring the dielectric permittivity of the ceramic discs, the moisture content of the discs can be estimated. The matric suction in the ceramic discs is then inferred based on the known soil water retention curve of the ceramic discs. When the WPS sensor is placed in contact with soil, the matric suction in the ceramic discs and the soil equilibrate over time.

This process occurs due to the physical transfer of water between the ceramic discs and the surrounding soil. The rate of this equilibration is therefore a function of the hydraulic conductivity of the soil and the suction gradient between the ceramic discs and the surrounding soil [8]. Each TEROS 21 sensor is factory calibrated and only interpreted suction values are provided during use. This sensor type is referred to as the "WPS" sensor in this paper.

The second sensor type is the TUKS tensiometer as described by [9]. This sensor is a High-Capacity Tensiometer (HCT) and is constructed at the University of Pretoria. A HCT differs from a conventional tensiometer in that water pressures below 0 kPa absolute can be measured. This is possible due to the inclusion of a high air entry ceramic and a comprehensive saturation procedure which removes entrapped air from the tensiometer and minimises potential nucleation sites where cavitation can occur [10].

The TUKS HCT comprises a high air entry ceramic disc and a micromachined pressure sensor adhered together. A water reservoir fills the gap between the two components. Pore water pressure is directly measured through the exchange of water between the pores of the soil and the pressure sensor (via the ceramic and water reservoir). For a given soil hydraulic conductivity, it is therefore expected that a change in pore pressure would be recorded faster for the HCT when compared to the WPS, simply due to the size of the associated ceramic discs (see Fig. 3a). This sensor type is referred to as "HCT-epoxy cased" sensor in this paper.

The third sensor type is an improvement on the epoxy-cased TUKS tensiometer where a steel casing is used. This sensor type is referred to as "HCT-steel cased" sensor in this paper. Saturation and calibration of the HCTs were performed in accordance with the recommendations of [11].

A summary of key aspects of the three sensor types is provided in Table 1 and photographs of these sensors are shown in Fig. 3a.

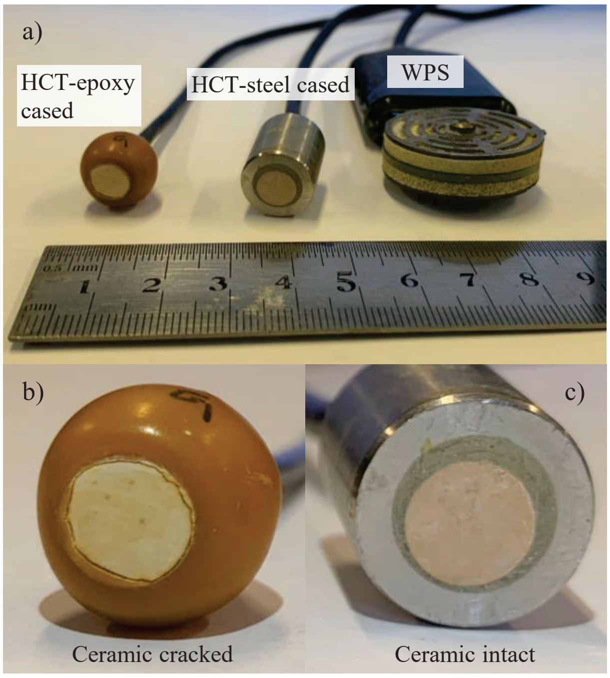

Fig. 3. Photographs of the three sensors after the test

3 Drying Box Experiment

Although the goal is to monitor the suction in an active tailings dam, it is often prudent to perform laboratory trials to evaluate the performance of the proposed sensors first. A Drying Box experiment is a common experiment for tailings material where the tailings is deposited in a slurry form in layers in a large instruments container and the subsequent drying is observed in a controlled environment.

Previous studies have incorporated mid-plane suction probes to measure soil suction [12] or standard tensiometers [5]. However, the mid-plane suction probe can be tedious to construct and calibrate, and the standard tensiometers are limited in their operating range. These studies were also conducted over a relatively short period: 9 and 70 days, respectively. Therefore, there was limited investigation into the long-term reliability of the sensors which may be a concern in mine tailings.

For this study, a 1 kL Drying Box experiment was conducted at the University of Pretoria's geotechnical laboratory. A schematic cross section of the Drying Box

 https://doi.org/10.1051/e3sconf/202338216006

is shown in Fig. 4. Two identical setups were installed, with each setup comprising one of the three sensor types. A total of six Deposition Events (DE) and four Rainfall Events (RE) were conducted over the monitoring period. The final tailings elevation is shown for each DE with the corresponding week for reference.

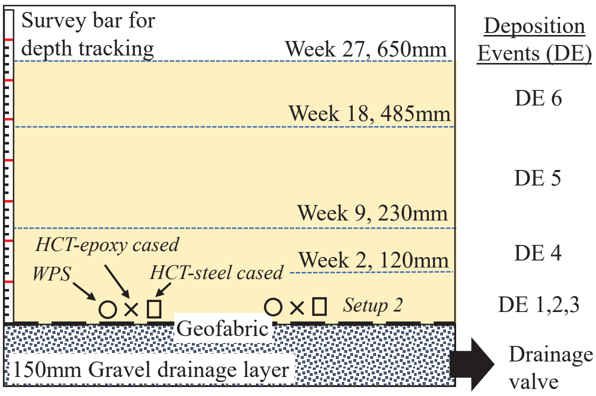

Fig. 4. Schematic cross section of the Drying Box

Selected photographs taken during the test are shown in Fig. 5. Fig. 5a shows a layout of the two setups placed on top of the geofabric. The HCTs were installed after the placement of the tailings deposition layer and are therefore not shown in the image. The additional sensors are part of a larger investigation into the behaviour of mine tailings as described by [1].

Fig. 5b shows the drying cracks that had developed on the surface of the tailings after nine weeks. These cracks are critical for the drying and desiccation process of upstream constructed tailings dams and indicate that the Drying Box is appropriately simulating the site conditions. The survey bar for depth tracking and light to speed up the drying process are also visible in the figure.

4 Results

The results from the Drying Box experiment are shown in Fig. 6. Fig. 6a shows the measured suction values from the three sensor types over the entire duration of the test. The suctions measured by the WPS are shown in blue, and the suctions measured by the HCT-epoxy cased and HCT-steel cased sensors are shown in orange and yellow, respectively. The six deposition events and four rainfall events are also indicated for reference.

Fig. 6b shows selected data from the test, specifically the drying periods for the first four DEs. The intent of the figure is to highlight the excellent correlation between the HCT-epoxy cased and HCT-steel cased between Weeks 1 and 15. However, there is a divergence between the tensiometers during Week 16. Upon recovery of the tensiometer at the end of the test, it was found that the ceramic had cracked. This was only noted on the epoxy cased tensiometers and not on the steel cased tensiometers. Fig. 3b shows an HCT-epoxy cased sensor with a similarly cracked ceramic while Fig. 3c shows an HCT-steel cased sensor with an intact ceramic. For monitoring of gold tailings, steel casings are recommended to reduce the likelihood of cracking of the ceramic.

Also shown in Fig. 6b is the performance of the WPS at low suction values. In particular, the periods directly after DEs 1 to 4 as indicated with the dotted lines. During these periods, the suction values were close to zero and in fact some positive pore pressures were measured. Both the epoxy-cased and steel-cased HCTs were able to capture these low suction values, however, the WPS was not. This was expected, as the ceramic used for the WPS has an AEV of approximately 9 kPa [7]. For field monitoring of gold tailings where low suction values are expected, the WPS is not recommended.

Fig. 6c shows the same period as Fig. 6b but this time highlights the slower response of the WPS due to a change in suction. Two particular examples are highlighted. The first is during Week 8 where both HCTs recorded a suction value of 28 kPa but the WPS only showed a suction of 7 kPa. This slow response is also seen during Week 15 where both HCTs recorded a suction of 20 kPa but the WPS only showed a suction of 6 kPa. This slow response is not adequate for monitoring of gold tailings where rapid changes in suction are expected due to routine deposition and drying events as well as rainfall.

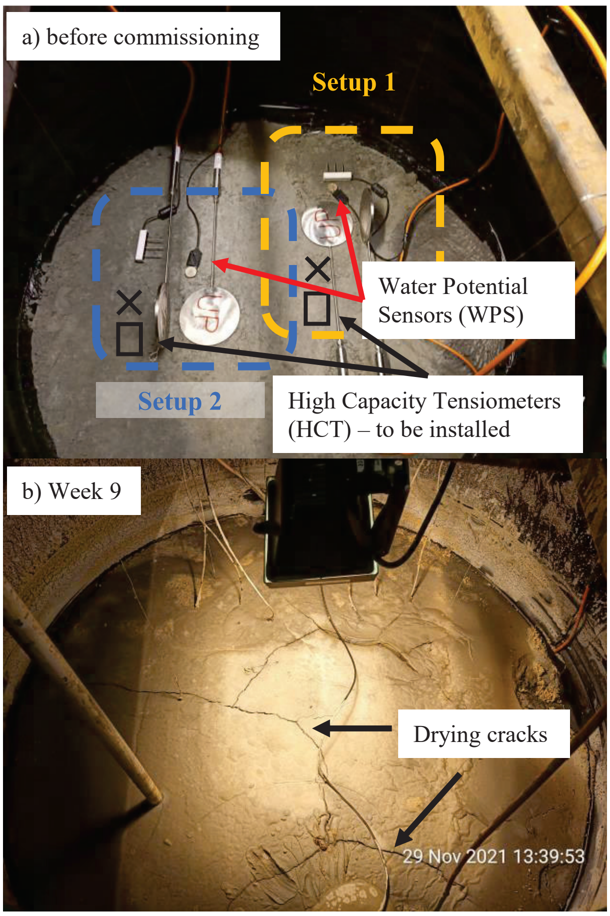

Fig. 5. Drying Box experiment

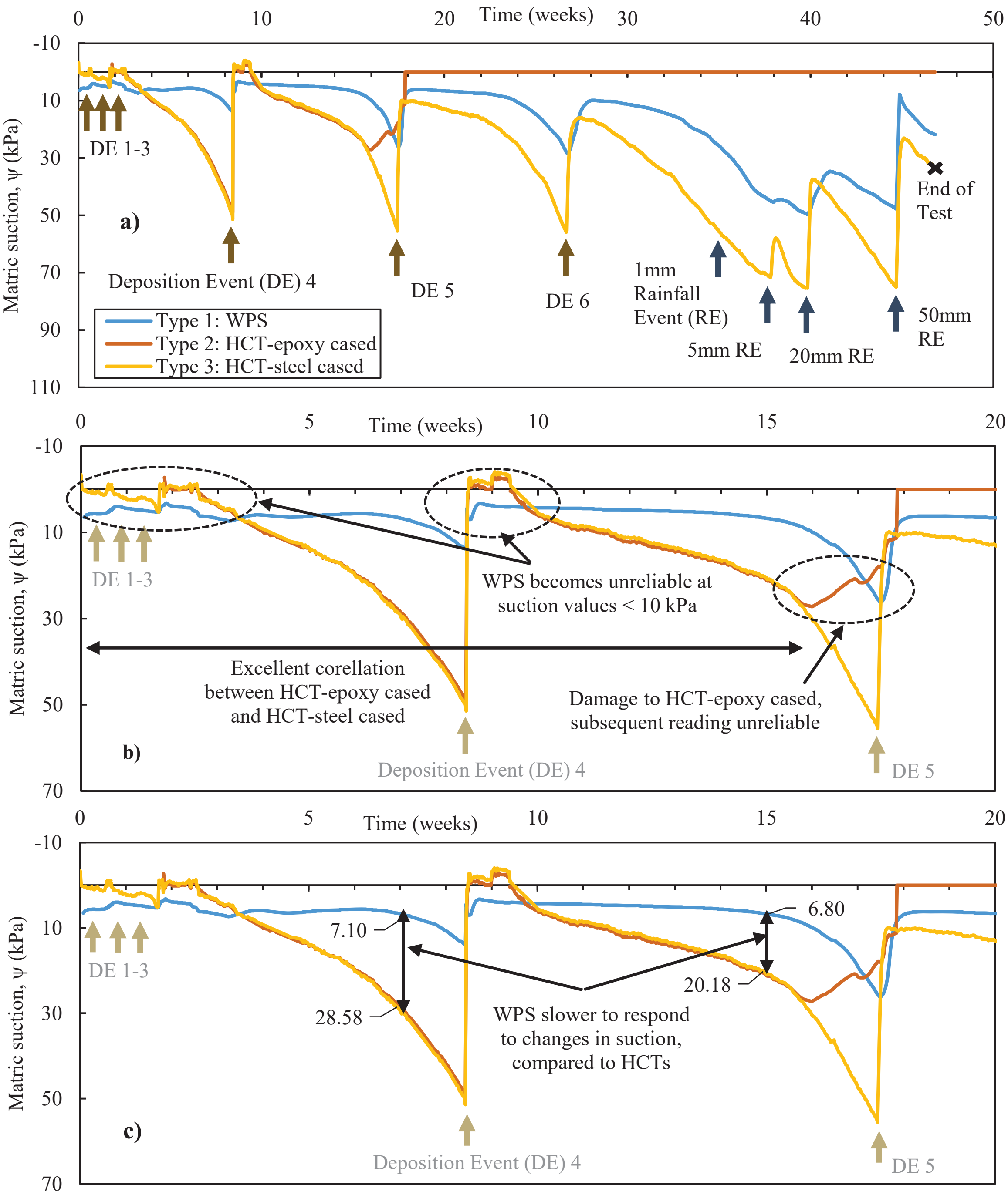

Fig. 6. Suction measurement results from the Drying Box experiment for the three sensor types

Table 1: Key aspects of the three sensor types

Sensor Type	Description	Range	Accuracy	Reference
Type 1: WPS Sensor	A commercially available solid phase water potential sensor	-9 kPa to -100 MPa	10% of reading +2 kPa*	[7]
Type 2: HCT-epoxy cased	An in-house tensiometer constructed using silicon micromachined pressure sensors with an epoxy casing	+500 kPa to -500 kPa	0.6% Full Scale Output (FSO)	[9,11]
Type 3: HCT-steel cased	An in-house tensiometer constructed using silicon micromachined pressure sensors with a steel casing	+700 kPa to -1 697 kPa	0.6% FSO	[13]

*accuracy rating only provided for suction values between 9 and 100 kPa.

5 Conclusions

A long-term Drying Box experiment using gold tailings was conducted in the geotechnical laboratory at the University of Pretoria. The gold tailings was sourced from an active tailings dam on the East Rand. The aim of the experiment was to investigate the performance of three sensor types on the long-term monitoring of suctions in the gold tailings. The following was found:

1. The WPS is a commercially available sensor and has the advantage of not needing to be calibrated. However, the limited operating range at low suctions and the relatively slow response of the sensor compared to the response of the HCT make the sensor unsuitable for monitoring of gold tailings. Despite these limitations, the high capacity of the sensor (i.e. its resistance to cavitation) makes the case for installing this sensor as a supplementary sensor to a HCT.
2. The epoxy-cased TUKS tensiometer (HCT-epoxy cased) provided a rapid response and was initially reliable. However, after a few weeks it proved susceptible to cracking of the ceramic which rendered the sensor inoperable. The use of the epoxy-cased TUKS tensiometer is therefore not recommended for long-term monitoring of gold tailings.
3. The steel-cased TUKS tensiometer (HCT-steel cased) proved the most effective for measuring low suction values, rapid changes in suction values and proved resilient to ceramic cracking. This sensor type is therefore recommended for use for long-term monitoring of suctions in gold tailings.

The authors gratefully acknowledge and thank Fraser Alexander Tailings and the South African National Research Foundation (NRF) for financial support provided to undertake this research.

References

1. S.W. Jacobsz, Y. Narainsamy, *J. of the South. Afr. Inst. of Min. and Met.*, **122**, 6, 267–273. (2022)
2. ASTM. ASTM D2487-17: Standard practice for classification of soils for engineering purposes (unified soil classification system), (2017)
3. C.P.K. Gallage, T. Uchimura, *Soils and Foundations*, **50**, 1, 161–172 (2010)
4. M. Theron, *Soil suction in mine tailings*. MEng Thesis, University of Pretoria, Pretoria (2006)
5. F. Daliri, *The influence of desiccation and stress history on monotonic and cyclic shear response of thickened gold tailings,* PhD Thesis, Carleton University, Ontario (2013)
6. D.G. Fredlund, A. Xing, *Can. Geo. J.*, **31**, 4, 521–532 (1994)
7. METER Group. *TEROS 21 User manual* (2020), Available at: http://library.metergroup.com/Manuals/20854_TEROS21_Gen2_Manual_Web.pdf
8. R. Vandoorne, P.J. Gräbe, G. Heymann, *Trans. Geo.,* **31**, 100675. (2021)
9. S.W. Jacobsz, Low cost tensiometers for geotechnical applications, *In Physical Modelling in Geotechnics*, 305–310, CRC Press (2018)
10. W.A. Take, M.D. Bolton, *Géotechnique*, **53**, 2, 159–172 (2003)
11. P. le Roux, *The measurement of soil-water retention curves using the tensiometer method*, MEng Thesis, University of Pretoria, Pretoria (2019)
12. D. Westraad, *Suction induced shear strength of gold mine tailings*, MEng Thesis, University of Pretoria, Pretoria (2004)
13. S.W. Jacobsz, *J. of the South Afr. Inst. of Civ. Eng.*, **27**, 1, 24–26 (2019)